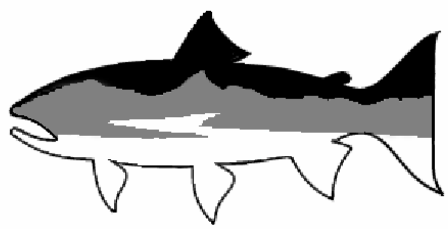
Interagency Regional Monitoring

Northwest Forest Plan

Aquatic and Riparian Effectiveness-Monitoring Program



2001 Pilot Report

Kirsten Gallo, Chris Moyer, and Steve Lanigan

Aquatic and Riparian Effectiveness-Monitoring Core Team

USDA Forest Service Pacific Northwest Regional Office

Bureau of Land Management Oregon State Office

April 2002

A copy of this report is also available on our Watershed Monitoring Website:

Contents

List of Tables

List of Figures

List of Appendices

Summary

A pilot project was conducted during the 2001 field season to test whether intensive subsampling could adequately characterize watersheds and to establish a data quality assurance program. Protocols for conducting upslope and riparian vegetation and roads analyses were also developed. Finally, a decision support model was constructed to evaluate the condition of individual sample reaches and watersheds.

To determine whether subsampling inherent in the intensive surveys would adequately characterize watersheds, we compared intensive survey data with extensive full-census survey data. For channel morphological indicators such as bankfull width: depth and entrenchment ratio, the difference between the two surveys was not significantly different from zero. However, pool frequency was higher in the intensive surveys than the extensive survey.

For the intensive surveys, an independent crew resampled two randomly-selected sites in each watershed in an effort to estimate the variance associated with field sampling. Channel morphological characteristics were very close in the two survey efforts, wood and pool frequency were more variable, and substrate estimates (D_{50} and percent fines) were the most variable of the indicators. However the difference between the two surveys was not significantly different from zero for any of the indicators.

Vegetation composition for riparian and upslope areas was determined using data layers developed by the Interagency Vegetation Mapping Project for Oregon and Washington and CalVeg in California. Both of these layers were constructed based on Landsat Thematic Mapper data. Vegetation was divided into the following classes: non-forest, pure conifer, pure hardwood, and mixed forest. Conifers in pure and mixed forest were further classified by seral stage.

Reach and watershed-level evaluations were conducted using a decision support model. The model and evaluation criteria are currently undergoing peer review. The model structure, evaluation criteria, and results will be shared with local managers when the peer review is complete.

We encountered several difficulties in the field sampling, notably the loss of watersheds from the sampling effort because they were dry or physically too large to sample. Also we encountered very few non-constrained or response reaches, which may make in-channel trend detection in the watersheds extremely difficult.

Introduction

Background

The Northwest Forest Plan (NFP) was approved in 1994. The Plan includes an Aquatic Conservation Strategy that requires the protection, rehabilitation, and monitoring of aquatic ecosystems under the Plan's jurisdiction (USDA-USDI 1994). The Aquatic and Riparian Effectiveness Monitoring Plan (AREMP or the monitoring plan) was developed to fulfill these monitoring requirements. The final monitoring plan was approved March 2001. The monitoring plan was designed to assess the condition of aquatic, riparian, and upslope ecosystems; develop ecosystem management decision support models to refine indicator interpretation; develop predictive models to improve the use of monitoring data; provide information for adaptive management by analyzing trends in watershed condition and identifying elements that result in poor watershed condition; and provide a framework for adaptive monitoring at the regional scale (Reeves et al. 2001). Monitoring is conducted at the subwatershed scale (USGS 6th-field hydrologic unit code). These subwatersheds (hereafter referred to as "watersheds") are approximately 10,000-40,000 acres in size.

Collection of field data began summer 2000 in four watersheds. The goal of the 2000 sampling was to test sampling protocols and determine the funding level and crew structure needed to implement the monitoring plan (Moyer et al. 2001). A pilot project was conducted in 2001 in 16 watersheds to continue the refinement of the protocols and to answer other questions related to implementing the monitoring plan (see Monitoring Objectives/Questions section below). Here we present the results from the 2001 pilot, highlighting the progress made by the monitoring plan thus far.

Pilot Program Monitoring Objectives

A pilot project for the monitoring plan was conducted during the 2001 field season. Sixteen watersheds spread throughout the NFP area were included in the pilot. The objectives of the pilot program included:

- Comparing data generated by intensive subsampling efforts with data generated by extensive full-census sampling efforts.
- Developing a data quality assurance/quality control program.
- Developing a data analysis protocol for upslope and riparian vegetation and roads.
- Constructing a decision support model and defining evaluation criteria for assessment of watershed condition.

A complete discussion of each of these objectives is provided in subsequent sections. Included is a brief introduction, methods, results, and the next step needed to complete the project. The Logistical Considerations section describes the next step(s) in the evolution of the module, including a discussion of problems encountered during the 2001 pilot, the budget and personnel required to accomplish the tasks assigned to the module, and the effort underway to coordinate the monitoring plan with other monitoring programs conducted by state and federal agencies in the NFP area.

Field Efforts

Watershed and Site Selection

Watersheds must contain a minimum of 25 % federal ownership (USDA Forest Service, USDI Bureau of Land Management [BLM], or USDI National Park Service) along the total length of the stream (1:100,000 National Hydrography Dataset [NHD] stream layer) to be considered for sampling in the monitoring plan. Of the watersheds that meet the ownership criteria, 16 were randomly selected for inclusion in the pilot program (Table 1, Figure 1). Selection of the watersheds was stratified by physiographic province to ensure that the full geographic extent of the NFP area was included in the pilot.

To allow for temporal differences in stream flow across the NFP area and to minimize the impact of a drought occurring throughout the Pacific Northwest, crews sampled all watersheds in Oregon, then California, and finished the field season in Washington. Within each state, watersheds were sampled in random order by a randomly selected crew. A single crew conducted all sampling within individual watersheds. Two sites in each watershed were randomly selected and resampled for data quality assurance. In addition to the intensive surveys, extensive surveys were conducted in eight of the 16 watersheds. Each of the field efforts listed here, intensive survey, extensive survey, and the quality assurance program are described in detail in the following sections.

Intensive subsampling versus extensive full-census survey comparison

Objective:

To compare data collected using intensive and extensive survey to determine whether the intensive survey effort adequately captures in-channel watershed characteristics.

Intensive survey method

Eighty potential site locations within each watershed (Figure 2) were randomly selected along the stream channel using a generalized random tessellation stratified survey design. This procedure, developed by the US Environmental Protection Agency, guarantees a spatially balanced sample. Field crews began sampling at site location 1 and continued sequentially through the list until the 8-day time period expired. Sites were excluded from the survey for the following reasons:

- The site was located on private land or could not be accessed due to private land.
- The site was not safely accessible; i.e., the site could not be reached without putting the crew in danger.
- The stream did not meet the minimum stream size criteria of 1 meter wetted width and 0.1 meters deep in riffle habitats or pool tail crests.
- The stream was too large to physically sample (i.e., not wadeable) and was a safety concern for crews.
- The site was located in a lake, pond, or glacier.

On average, six sites were sampled in each of the watersheds (range = 4 – 10). This effort represented an average of 6 % of the total length of the stream (range = 4 to 9 %). The number of sites sampled in each watershed was typically a function of access. That is, the longer it took the crew to access sites, the fewer the sites that could be sampled.

At each site location, data on 19 indicator variables were collected (Table 2). Stream morphological characteristics were determined from cross-sectional and longitudinal profiles measured using a laser rangefinder. Six cross-sectional profiles were measured in constrained reaches, and 11 were measured in non-constrained reaches. Cross-sectional profiles were evenly spaced along the length of the sample reach (reach length = 20 * bankfull width). Data from the cross-sectional profiles were used to calculate bankfull width: depth and entrenchment ratio (Table 3). A minimum of 100 points was measured along the longitudinal profile, with additional measurements taken at each pool head, maximum depth, and tail crest. Data from the longitudinal profile were used to calculate sinuosity, gradient, pool frequency and residual pool depth (Table 3). Wood pieces (minimum size = 0.3 m diameter at breast height, 3 m long) were measured and counted within the sample reach. Configuration and location within the channel was also recorded.

Field analysis of stream water included dissolved oxygen, pH, conductivity, and local temperature collected using MultiLine P4 water meters. Water samples were collected and analyzed in the laboratory for total Kjeldahl nitrogen and total phosphorus. Temperature data loggers were placed during the summer months at the lowest part of the watershed located on federal land. From these temperature data, the seven-day average maximum temperature was calculated.

Biological data at each site were obtained by sampling fish, aquatic and terrestrial amphibians, benthic macroinvertebrates, and periphyton. Fish and aquatic amphibians were sampled using a single pass with an electrofisher. Terrestrial amphibians were sampled using a time/ area constrained search. Each fish and amphibian captured was identified and enumerated. Approximately 20 % of the organisms captured with the electrofisher were measured for total length (fish) or snout-vent length (amphibians) then returned to the stream. All terrestrial amphibians captured were identified, counted, measured for snout-vent length, and then returned to the area captured. Eight macroinvertebrate subsamples were taken in riffle habitats using a kick net. Eleven subsamples were taken for periphyton, spread evenly along the length of the reach. Both macroinvertebrate and periphyton samples were preserved and returned to the laboratory for taxa identification and enumeration. References and additional details related to the sampling methodologies are included in Appendix A.

Extensive survey method

Extensive surveys were conducted in eight watersheds for comparison with the intensive survey data. The goal of the comparison was to determine whether the subsampling inherent in the intensive survey would provide an adequate representation of the watershed. We assume that the results of the extensive survey reflect the in-channel characteristics of the watershed. The extensive survey was conducted using the Forest Service Region 6 Stream Inventory protocol (USFS, 2001). Data collected in the extensive survey include wood and pool frequency, bankfull width and depth, and floodprone width (Table 2).

The extensive survey began at the mouth of the watershed (or lowest part of stream on federal land) and continued upstream until the stream was too small to sample, according to the limits of the intensive survey (see Intensive Survey section above). All creeks in the watershed that contained intensive survey sites were included in the extensive survey. The entire length of each stream was classified into pool or riffle habitat units. Length and average width were estimated for every habitat unit. Measurements for length and average width were taken in the first ten habitat units and every tenth pool and riffle unit thereafter, using a tape. In each pool, maximum depth and tail crest depth were measured with a stadia rod. Measured units were used to obtain a calibration ratio used to correct the length and width of the estimated units (Hankin and Reeves 1988). The protocol for sampling large wood was the same as that used in the intensive survey; except that the number of pieces were tallied within habitat units rather than longitudinal sections. Bankfull width: depth, entrenchment ratio, wood frequency, pool frequency, and residual pool depth were calculated as described for the intensive survey (Table 3). Additional details on the extensive survey protocol are included in Appendix A.

Data Analysis

Data were compared for bankfull width: depth, and entrenchment ratio, and pool frequency. Wood frequency data are not yet available. For bankfull width: depth, entrenchment ratio, and residual pool depth, average estimates were calculated using all habitat units measured in the extensive survey. These data from the extensive survey were compared with the mean estimate across all sites sampled in the intensive survey. Pool frequency ($\# \cdot 100\ m^{-1}$) was calculated from the total number of pools tallied in the extensive survey and the total length of the survey. Extensive pool frequency was compared with mean pool frequency across all sites intensively sampled in the watershed.

Statistical comparisons were made using a paired sample t-test with two tails, to determine whether the difference between the intensive and extensive survey was significantly different from zero. Statistical analyses were conducted using S-Plus software, Version 6 (Insightful Corp. 2001). To reduce the likelihood of Type II error, alpha was set at 0.05 prior to conducting the analyses.

Results

The intensive survey appears to reflect conditions in the watershed for entrenchment ratio and bankfull width: depth. Entrenchment ratio in the intensive survey was equally over- and underestimated compared to the extensive survey (Figure 3A). Overall the difference between the extensive and intensive entrenchment ratios was not significantly different from zero ($t=0.61$, $df=11$, $p=0.55$). In general, bankfull width: depth calculated from the intensive survey tended to be lower than that from the extensive (Figure 3B). However the difference between the two surveys was not significantly different from zero ($t=-0.38$, $df=10$, $p=0.97$).

Higher pool frequencies were measured in the intensive survey than the extensive survey (Figure 3C). Statistically the difference in pool frequency between the two surveys was significantly different than zero ($t=-3.42$, $df=11$, $p<0.01$). The difference between the two surveys was probably due to inclusion of small or shallow pools in the intensive survey that were less likely to be split out during the coarser extensive survey. Therefore we examined the frequency of pools with residual depth greater than 1m. Deep pools were relatively rare in the watersheds sampled; consequently sample size for the comparison decreased. Frequency of deep pools was also higher in the intensive survey than the extensive survey (Figure 3D), however overall the difference between the surveys was much lower. The low sample size precluded statistical analysis.

Implementing the two kinds of surveys

Extensive surveys are frequently implemented when conducting watershed inventory: that is, a census of watershed characteristics, whether the characteristics are physical (e.g., log jams, deep pools, or fish migration barriers) or biological (e.g., fish species composition). Extensive surveys capture characteristics that are rare in the watershed. Random subsampling designs (such as the intensive site surveys) were developed to characterize watersheds while avoiding the time and expense of surveying entire watersheds. However, subsampling only captures characteristics that are frequently observed and is not likely to capture uncommon watershed characteristics.

The extensive survey design we used was considerably less expensive to conduct compared to intensive surveys. However, the quantity and quality of the extensive data collected were also lower. Only five of 19 indicators were collected during the extensive survey (Table 2). Further, the laser rangefinder used to map the stream profiles has an accuracy of ± 1 cm at 100m. In the extensive survey, length and width of the habitat units were estimated and approximately 10 % of the units were measured to correct the estimates. At best, habitat units were estimated to the nearest half-meter, which is not adequate for determining changes in the channel profile over time. Common sense suggests that if all the attributes measured with intensive surveys were done during the extensive surveys, the latter's costs would be substantially greater.

Survey Variability

Intensive survey locations were resampled in 2001 to examine the variance associated with the field data collection. Data collected during the resample visit was not significantly different from the original sampling for any of the indicators (see Data Quality Assurance section below). We did not conduct duplicate surveys on any of the extensive surveys; therefore we cannot evaluate the repeatability of the extensive surveys. However, Roper and Scarnecchia (1995) found that it was difficult to classify habitat units consistently, even with experienced observers. Further, observer variability was affected by stream attributes such as gradient and wood frequency (Roper and Scarnecchia 1995).

Another downside of the extensive survey is that the data are less flexible. For example, with the mapped stream profiles generated in the intensive survey, it is possible to change the definition of a pool (perhaps add a depth requirement) and reclassify all of the habitat units using the longitudinal profile. With extensive survey data, reclassification (or other examination) would not be possible and data would be lost.

Conclusion

We conclude that intensive surveys provide the most cost effective method to collect watershed condition monitoring data that will be able to show relatively show changes in condition over time.

Developing a Data Quality Assurance Program

Objective

Development of a data quality assurance program to assess variance associated with field sampling and to ensure watershed condition changes can be detected.

Introduction

A quality assurance (QA) program was implemented to quantify variance associated with the field data collection efforts. Data QA is necessary to ensure that the data collected are technically sound. The goal of this program was to assess the total variance associated with sampling including natural and temporal variance, observer bias, and sampling error. We did not attempt to quantify individual sources of error. The results of the program allow us to define the level of precision associated with each indicator estimate or state the probability that the estimate is correct (Taylor and Stanley 1983). The QA program was applied only to the intensive survey effort.

Methods

To examine the variance associated with the intensive sampling effort, two randomly selected site locations were resampled in each watershed. A single crew was chosen at random to resample all watersheds within a single state. This crew did not complete any of the original sampling. During the resample, data were collected for the same suite of indicators (Table 2) using the same collection methods as the original intensive survey (Appendix A). Each watershed was resampled within two or four weeks after the original sample. In general, flags and other markings associated with the original sampling effort were left at the site and used by the second crew.

Data analysis

Statistical comparisons were made using a paired-sample t-test, to determine whether the difference between the original and the resample surveys was significantly different from zero. Statistical analyses were conducted using S-Plus software, Version 6 (Insightful Corp. 2001). To reduce the likelihood of Type II error, alpha was set at 0.05 prior to conducting the analyses.

Results

The difference between the original and QA surveys was minimal for the channel morphological indicators (Figure 4). With the exception of a couple of points, both channel sinuosity and percent slope values were very close to the 1:1 line (Figure 4A and B, respectively). Statistically, the difference between the original and the QA survey was not significantly different from zero for either sinuosity ($t=-1.27$, $df=28$, $p=0.21$) or percent slope ($t=1.42$, $df=29$, $p=0.16$). Two of the four entrenchment ratio comparisons fell on the 1:1 line (Figure 4C). The difference between the two surveys was not statistically different from zero ($t=1.42$, $df=4$, $p=0.23$). Very few entrenchment ratios could be compared between the two surveys (4 of 32 surveys). Frequently, the crews failed to capture flood prone, because they did not sample far enough out from the stream channel, therefore we could not calculate entrenchment ratio. Also, transects that were supposed to be measured for flood prone were randomly chosen (two per site). In several cases, the same transects were not measured for flood prone in the two surveys. Bankfull width: depth fell on both sides of the 1:1 line, and was not significantly different in the two surveys (Figure 4D; $t=-0.42$, $df=30$, $p=0.68$).

Both wood and pool frequency were more variable than the morphological indicators. Wood frequency fell on both sides of the 1:1 line (Figure 5A); the difference between the two surveys was not significantly different from zero ($t=1.45$, $df=30$, $p = 0.16$). Pool frequency was clustered around both sides of the 1:1 line (Figure 5B). The difference between the original and QA survey for pool frequency was not significantly different than zero (t=-1.41, df=28, p=0.17).

The substrate measurements were the most variable of the survey comparison. D_{50} tended to be lower in the QA survey than the original survey (Figure 6A), however the difference between the two surveys was not significantly different from zero (t=0.79, df=31, p=0.44). Percent fines had the widest spread around the 1:1 line of any indicator (Figure 6B), and the QA survey tended to have a higher percent fines, however the difference between the two surveys was not significantly different from zero (t=-0.70, df=24, p=0.49).

The next step – producing a plan

Additional analyses will be conducted using the 2001 QA data. Signal to noise ratios will be calculated for each indicator. These ratios are useful for examining the variance of the indicator observed (signal) with the "noise" variance resulting from field measurement (Kaufmann et al. 1999). A redundancy analysis will also be performed to examine the redundancy of the indicator data collected in an effort to reduce the suite of indicators sampled. Finally, we will attempt to determine the number of sample sites that will be required to detect changes in the watersheds of the magnitude that land management activities are expected to produce.

In the 2002 field season, additional parts of the QA program need to be implemented, including isolating the different sources of variability and testing the adequacy of the protocols. The sources of variability examined will include natural and temporal variance, observer bias, and sampling error. We will continue with the resampling program, we would like to have multiple crews sample the same location to get a better estimate of within crew variance. We also need to test the adequacy of the protocols. For example, substrate data were highly variable between the original and the resample survey. If we have each crewmember measure the same 100 rocks, we can determine how much of the variance is due to sampling error and how much is due to natural variability within the sample reach. Once we determine how much variance is due to different sources, we can assess whether the protocols and the sampling intensity are adequately robust to detect change over time in the watersheds. We will also examine the results of other studies examining variability and incorporate them as appropriate. A peer-reviewed QA plan will be written to document the processes used to ensure quality data collection, storage, and sharing with other groups.

Developing Upslope and Riparian Protocols

Objective

Develop a data analysis protocol for upslope and riparian vegetation and roads

Vegetation

Vegetation composition, seral stage, and percent cover in the riparian and upslope areas of the watershed are included in the monitoring plan's evaluation of watershed condition. Upslope vegetation (all vegetation > 100 m from the stream channel) and riparian vegetation data (all vegetation < 100 m from the stream channel) were collected from the vegetation layer developed by the Interagency Vegetation Mapping Project (IVMP) in Oregon and Washington, and the CalVeg layer developed in California. Both layers were constructed using Landsat Thematic Mapper remote sensing data. Riparian vegetation data were collected on all streams in the watershed that appear on the 1:24,000 stream layer. For the purposes of the pilot project, aerial photographs are being interpreted for each watershed. These data will be compared with that derived from the IVMP to test for accuracy and precision of the data. The data parameters collected are the same for both types of vegetation.

From the data sources described above, vegetation was classified into the following categories:

- *Non-Forested/Grass-Forb* - Areas not producing or capable of producing a stand of trees in next 10 years. These areas include pastures, shrubs, meadows, lakes, active landslides, talus slopes, rock formations, buildings and other barren ground. Clear-cuts were not included in this category.
- *Deciduous* **-** Stands composed of > 90 % deciduous species.
- *Mixed* **-** Stands that contain both conifer and hardwood species. The percent of each type of vegetation (coniferous or deciduous) was estimated to the nearest 10%. Coniferous trees were further classified by seral stage (definitions of seral stage classes follow).
- *Conifer* – Stands composed of at least 90% coniferous species. Conifers in both pure and mixed stands were classified by seral stage using the following definitions from Hemstrom et al. (1998):
    - *Early Seral* - recent clear cuts to stands with trees less than 25 cm (10 in) diameter at breast height (dbh). Approximate stand ages from 0 to 24 years old.
    - *Mid Seral* **-** Stands trees from 26 cm to 52 cm (10 - 20 in) dbh. Approximate stand ages from 24 to 80 years old.
    - *Late Seral* **-** Stands with trees greater than 53 cm (20 in) dbh. Approximate stand ages >80 years old.

Roads analyses

Road density and frequency of road crossings were calculated for input into the decision support model. For these analyses, road and stream geographical information systems (GIS) coverages were pieced together from layers developed by the Forest Service and BLM. The quality and density of the coverages varied depending on the source and the ownership of the land. Mapping on private lands is often less intensive. Roads were included in the analysis if they were “classified”. Classified roads are defined as

> “Roads wholly or partially within or adjacent to National Forest System lands that are determined to be needed for long-term motor vehicle access, including state roads, county roads, privately owned roads, National Forest System roads, and other roads authorized by the Forest Service (36 CFR 212.1).”

The source of the road definition is FSM 7700 – Transportation System Chapter 7700-Zero Code, WO Amendment 7700-2001-1.

Road density (miles of road per square mile of watershed) was calculated for both the upslope (> 100m from stream) and riparian area (< 100m from stream). For these analyses, the stream layer was buffered 100 meters each side and overlaid with the roads to calculate road density. The number of road crossings was estimated by finding the intersection of roads and streams. These results were visually inspected to identify possible digitizing errors. Erroneous crossings were removed from the analysis.

EMDS Modeling Effort

Objective

Construct a decision support model and define evaluation criteria for assessment of watershed condition

Introduction

A decision support model was constructed to evaluate the condition of the watersheds sampled under the monitoring plan. Watershed condition was evaluated according to the objectives of the Aquatic Conservation Strategy (USDA-USDI 1994). A watershed was defined as being in "good" condition if the physical attributes were adequate to maintain or improve biological integrity, including diversity and abundance of species. Specific physical attributes included intact upslope and riparian habitats that were biologically and structurally diverse and functioned properly, i.e., stabilized banks, reduced sediment and nutrient input into the stream, and contributed wood to the stream channel. Flows had to be adequate to maintain or improve riparian and in-channel habitat. Chemical characteristics and water temperature must have been within a range that maintains biological integrity.

The Ecosystem Management Decision Support (EMDS) system is an application of the model framework that performs ecological analysis at any geographic scale. Knowledge base systems and GIS technologies are integrated in EMDS (Reynolds et al. 2000). A knowledge base is a meta database (that is, a large database with multiple variables) that provides a formal logic for interpretation of data (Waterman 1986, Jackson 1990). The model provides a formal framework for evaluating watershed condition. Within the framework, individual indicators are evaluated using fuzzy logic (described in Methods below). These evaluations are aggregated to produce an overall estimate of watershed condition.

The monitoring plan's model is composed of two knowledge bases, one that evaluates the condition of individual sample reaches (Figure 7), and another that evaluates condition at the watershed scale (Figure 8). Included in the reach condition knowledge base are all of the indicators collected in the field during the intensive sampling sessions (Table 2). The average of the reach condition values in a single watershed is passed to the watershed knowledge base and evaluated with the in-channel, upslope, and riparian indicators (vegetation and roads).

Several different operators may be used to aggregate evaluation scores for individual indicators. The “AND” operator calculates the weighted average of the subordinate goals. AND is biased towards the lowest evaluation score and if one of the subordinate goals has an evaluation score of –1 then the –1 score is passed to the next level of aggregation. The AND operand is typically used in cases where a single indicator is allowed to override the importance of other indicators. For example, high water temperatures can make a watershed unsuitable for fish, regardless of the condition of other indicators. In contrast to the AND, the “OR” operator passes the highest evaluation score. The “Addition” (+) operator calculates the sum of the evaluation scores of the subordinate goals. These scores are then evaluated on a scale dependent on the number of subordinate goals included in the calculation. For example, if evaluation scores from three subordinate goals were being aggregated by the + operand, the sum of the scores would be evaluated on a scale of –3 to +3 (i.e., (-1) * 3 to (+1) * 3). In general, the + function returns the mean of the subordinate evaluation scores (see Methods section below for explanation of curve types).

The operators allow scientists to take different perspectives on watershed condition. AND presents a worst case scenario of watershed condition, passing a score heavily influenced by the lowest subordinate evaluation score; whereas OR is an optimistic view, passing the highest evaluation score. The + operand assumes that good and poor attribute conditions balance each other out. In the monitoring plan’s decision support model, + operators were used throughout the reach and watershed knowledge bases. The only exception was water temperature, which was allowed to override other indicators. Construction of the knowledge bases was based on Figure 6 in Reeves et al. (2001). The knowledge bases were designed using NetWeaver knowledge base development software and evaluated using the EMDS system (Reynolds et al. 2000).

Methods

Data on each indicator outlined in the monitoring plan were evaluated in the model described above using fuzzy logic; which formally, is an extension of set theory. In each evaluation, a minimum of two (maximum of four) criteria was used: a value that is "good" or that fully supports the hypothesis that a particular resource is in acceptable condition (hereafter referred to as "good"), and a value that is "poor" or does not support the hypothesis that a particular resource is in acceptable condition (hereafter referred to as "poor"). Model evaluation employs algorithms based on fuzzy logic to determine where indicator data lie relative to the evaluation criteria. All indicator values less than the "poor" criterion fail to support the evaluation criteria and are consequently assigned an evaluation score of (-1). Conversely, all indicator values greater than the "good" criterion support are considered to provide full support for the hypothesis and are assigned an evaluation score of (+1). Data that fall between the "poor" and "good" criteria are assigned an evaluation score between (-1) and (+1) based on where the data lie between the criteria.

Two types of evaluation curves are used in the model. The first is a two-node curve, which may have a positive or negative slope (Figure 9A). The second is referred to as a type-2 curve that has four nodes (Figure 9B). In the latter case, a range of "good" values exists: for example, fish have upper and lower thermal tolerances. Temperatures outside this tolerance range may stress or kill fish; therefore "poor" criteria must be developed for both lower and upper temperature extremes.

For this report, indicators associated with in-channel, riparian , and upslope watershed conditions were evaluated using a single set of evaluation criteria (Table 4). Evaluation criteria were determined using the primary literature and data from various state and federal agencies. Many criteria came directly from the literature; others were derived using other means. Information on those criteria not from the published literature is included below.

In-channel stream morphological characteristics were evaluated by channel type. Definitions of channel type are those given by Rosgen (1994). To determine channel type, we used an Arc Macro Language script that uses gradient from 10 m digital elevation models and sinuosity from a stream layer. We typed the entire length of the stream within a watershed then determined channel type for each intensive survey reach. Rosgen (1994) provides the range of values of bankfull width to depth, entrenchment ratio, sinuosity, and gradient expected for each channel type, with a range of variance. For the evaluation criteria, the range identified by Rosgen (1994) for each indicator is used as the "good" criterion, and values outside the range of variance are considered "poor" (Table 5).

Evaluation criteria for upslope and riparian vegetation were derived from the Forest Service Current Vegetation Survey (CVS) data for the Mt. Hood National Forest. CVS plots were stratified by land use; the analysis for the evaluation criteria was conducted on plots located in unmanaged areas. Plots were then divided into riparian zone (valley or canyon bottom class) and upslope (all other classes). Percent cover for each of the vegetation classes (e.g. conifer by seral stage or deciduous) was determined in the riparian and upslope areas across all plots. These values were identified as the "good" criterion for each indicator. "Poor" values were calculated based on conversion of 30 % of mid and late seral stage to early seral stage.

Evaluation criteria values for wood and pool frequency were calculated as a function of bankfull width using equations derived by Bilby and Ward (1991). Bilby and Ward (1991) found that wood frequency was highest per unit channel width in old growth forests than in clear-cut forests. Wood frequency was the lowest per unit channel width in second growth stands. Consequently, Bilby and Ward (1991) constructed different relationships for old growth, second growth, and clear-cut watersheds. For our model, we classified the watershed as old growth, second growth, or clear-cut based on the dominant seral stage of the conifers in the pure and mixed stands. The y-values predicted by the equations were used as the “good” criterion. Standard error (SE) was calculated for each relationship. Indicator values less than predicted y – 1 SE were considered “poor.” The equations used to calculate wood and pool frequency are as follows from Bilby and Ward (1991):

Wood

Old-growth: $\log_{10}$ wood frequency = -1.12 * $\log_{10}$BFW + 0.46 ($r^2 = 0.69$)

Second-growth: $\log_{10}$ wood frequency = -1.23 * $\log_{10}$BFW + 0.28 ($r^2 = 0.75$)

Clear-cut: $\log_{10}$ wood frequency = 1.35 * $\log_{10}$BFW + 0.50 ($r^2 = 0.66$)

Pools

Old-growth: $\log_{10}$ pool frequency = -0.05 * BFW+ 1.49 ($r^2 = 0.64$)

Second-growth: $\log_{10}$ pool frequency = -0.08 * BFW + 1.59 ($r^2 = 0.70$)

Clear-cut: $\log_{10}$ pool frequency = -0.01 * BFW + 1.71 ($r^2 = 0.90$)

where BFW is bankfull width.

The next step

The model and evaluation criteria are undergoing peer review. Therefore, no results are presented here. The model structure, evaluation criteria, and results will be distributed to local managers when the review is complete. We are in the process of developing a set of evaluation criteria for each of the physiographic provinces (these values will also be peer-reviewed). In addition, a document is in preparation that identifies the criteria and describes how each value was determined. Once we have adequate data in each of the provinces, we will attempt to determine whether assessment of watersheds at the provincial scale is adequate. To conduct the analysis, we will determine how much of the variance of each indicator is explained by province by comparing the variance within province to the variance across provinces (Van Sickle and Hughes 2000). Criteria will then be modified as necessary.

An analysis of the model also needs to be conducted to determine how sensitive the model is to changes in individual attributes. We expect that the importance of individual indicators in determining watershed condition will change across provinces. The sensitivity analysis should determine which indicators tend to influence the overall watershed condition score, as well as the magnitude of change required in the indicators for trend detection. In short, we need to ensure that the model can detect changes of the magnitude that management activities are expected to produce. Finally, we will need to determine whether the protocols are adequate to detect the expected level of change. It is our intent that both the model structure and the evaluation criteria undergo peer-review during 2003.

Logistical Considerations

Problems encountered during the 2001 pilot

Numerous problems were encountered during the course of the field season. Among the most notable were dry watersheds, watersheds too large to sample, and a lack of non-constrained or response reaches. Two watersheds in the coastal California province were not sampled because the “stream” consisted only of localized pools. The problem was likely due to irrigation withdrawals and the drought. The coastal CA province has very little public land and the 6^{th} field HUC layer was not available for the province; therefore we were not able to sample in another watershed. At the advice of Tony Olsen (EPA - Corvallis), we recorded these watersheds and the reason for not conducting sampling there. Another of the watersheds selected for sampling was a spring fed system on the eastern side of the Cascades (west of Lake Billy-Chinook). Less than one mile of the total length of stream had sufficient water for sampling. We did sample in this stream because salmonids were abundant in the system; however we did in effect, attempt to charactere the entire watershed based on a non-typical portion of the stream.

Bankfull widths encountered during the season ranged from 3 to 80 meters. The streams in the Washington watersheds tend to be more widely variable in size than those in the other states. One watershed on the Olympic Peninsula was removed from the sampling because the stream was too large to sample and the tributaries were dry. By including composite watersheds, we will likely encounter many streams (or rivers) too large to sample.

The decision to monument cross-sectional profiles in non-constrained or response reaches was made during the RIAT meeting in January 2001. However, we encountered only three non-constrained reaches during the 2001 field effort. We defined non-constrained as a channel that has flood prone width > 2.2 * bankfull width. Possible solutions include 1) changing the definition of non-constrained to focus on valley width index rather than the active channel, 2) *a priori* stratification of the sample site selection based on constrained and non-constrained channels, or 3) simply placing a monument in the downstream-most non-constrained area in the watershed. Either of the first two alternatives is viable. Alternative two is the best way to ensure that an adequate number of non-constrained reaches are included in the sample to increase our ability to detect changes in the watershed. Alternative three does not maintain the probability structure gained by random sampling, and has other design issues.

State-Federal Coordination

Cooperative monitoring efforts between state and federal agencies are a natural extension of the monitoring plan as we look for ways to reduce costs and gain a better understanding of the interaction of federal, state, and private land watershed management actions within the NFP area. Monitoring plan personnel began hosting monthly meetings in November 2001 with state agency representatives from Washington, Oregon, and California to explore how to develop a monitoring partnership. The following is a summary of the discussions to date:

States' perspective on monitoring

Both Washington and California have legislative mandates to have monitoring programs in place by the end of 2002. Oregon is currently refining the monitoring program developed by the Oregon Watershed Enhancement Board. Although the state agencies are focused on developing monitoring programs to determine the effectiveness of state-funded restoration projects, they also recognize the need to include watershed condition as part of their assessment. Currently, the states do not have a standardized approach for monitoring watershed health.

Therefore, AREMP is of high interest because the states are looking for a cost effective method of monitoring watershed status and trend.

What are the key components to a successful monitoring partnership?

State and federal agency personnel identified the following: All agencies need to commit personnel and resources to long-term inter- and intra- agency monitoring programs. This commitment includes a coordinated regional monitoring team to provide oversight (facilitate) on the monitoring process. Support staff exchanges should occur to learn what each other are doing (e.g., new innovations) and conduct joint training for common protocols.

Complete coverage of core data for a representative subset of watersheds in CA, OR, and WA is needed, and there should be a high level of confidence in the quality of data collected. Data systems and protocols should provide a linkage for sharing data between agencies. This linkage includes a common database of core data, common protocols, and electronically connected systems.

The success of a state-federal monitoring partnership will be reflected in whether or not monitoring results are used for decision-making and adaptive management that provides more fish and restores watersheds to a better condition. To accomplish this, it is important that high quality monitoring results be presented to public and decision makers in a clear, timely manner leading to management decisions consistent with established goals, e.g., report cards, high trust in data, and data that serve a useful purpose. The efficiency and monitoring coverage is expected to be greater than what agencies could achieve separately. Other benefits of a monitoring partnership are the development of common tools for use in watershed analyses, ESA consultation, and identification of high priority restoration needs.

Action items in 2002 for the state-federal partnership team include:

- Identify the common objectives and needs for each agency. Examine existing resources and activities – what is the overlap between federal and state agencies?
- Push for an integrated land use/land cover/roads database.
- Develop options for picking common randomized sampling protocol that allows the greatest inference across the landscape.
- Conduct a map exercise to see where states might engage in state-federal “Pilot” monitoring effort. Conduct a pilot - if logistically feasible - in summer, 2002.
- Get the right people together to talk about data management/sharing.
- Create a list of key people who should be involved in a monitoring partnership.
- Engage National Marine Fisheries Service, Northwest Power Planning Council, Bureau of Reclamation, and Bonneville Power Authority. Work towards consistent approach among states and within Columbia River Basin.
- Get necessary commitment from state and federal agencies that they will commit time and resources to process.
- Have a protocol subgroup meet to discuss data quality/precision/confidence.
- Draft a 2-yr pilot proposal (with protocol) to share with agency policy makers to gauge internal support.
- Find opportunities for joint training or method exchange. Develop a strategy for quality control/assurance.

Budget information

The anticipated costs for future watershed surveys (four different scenarios), based on "lessons learned" during the 2000 and 2001 field seasons, are presented in Table 6. There are six major categories of AREMP operation including: 1) coordinating all field logistics (hiring, training, safety, payroll, travel, equipment purchases, etc); 2) handling the data (data processing; building, maintaining, revising the decision support model used to analyze the data, and specialized analysis); 3) creating and updating evaluation criteria; 4) overhead costs (building space, phones, support personnel, training, equipment); 5) GIS support; and 6) coordinating with state and federal land managers.

The total cost per watershed is \$58,000 and \$40,000 for the pilot efforts of 16 or 32 watersheds, respectively (Table 6). For full implementation of the monitoring plan (50 watersheds), the first year cost is approximately \$34,000 per watershed and in subsequent years the cost decreases to approximately \$30,000 per watershed (based on 2001 prices, salary costs, etc.). This results in a cost of \$5,000 per sample site, assuming an average of 6 sites continue to be sampled in each watershed. Although the salary component increases across all areas of operation as the number of watersheds increases, base and equipment costs stay constant and decrease, respectively, as the number of watersheds increases.

Costs are based on a five-person crew that spends eight days sampling in a watershed and completes one survey site each day. Resurveying watersheds for quality assurance also needs to be factored in. At a minimum, two sites should be resurveyed in each watershed. Based on our 2000 and 2001 surveys we are adding another crewmember (the "block leader") to conduct reconnaissance of the watersheds before field crews arrive on site, and assist in crew supervision in the field. Scouting watersheds involves, but is not limited to, tasks such as finding major access roads, camp sites, creek access points, determining which sample sites are suitable for survey, placement of water temperature probes, etc. The block leaders will also be responsible for general crew management tasks. Those tasks include checking the data for quality assurance, serving as the conduit for equipment repair and replacement, and serving as another check on to ensure to protocols are correctly followed.

References

Bilby, R.E. and J.W. Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in Southwestern Washington. Canadian Journal of Fisheries and Aquatic Sciences 48: 2499-2508.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Trans. Am. Fish. Soc. 117:

Hankin, D.G., and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45: 834-844.

Hemstrom, M., T. Spies, C. Palmer, R. Kiester, J. Teply, P. McDonald, and R. Warbington. 1998. Late-successional and old-growth forest effectiveness monitoring plan for the Northwest Forest Plan. Gen. Tech. Rep. PNW-GTR-438. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 37p.

Hicks, M. 2000. Evaluating standards for protecting aquatic life in Washington’s surface water quality standards – temperature criteria. Washington State Department of Ecology, Publication Distribution Center, P.O. Box 47600, Olympia, WA 98504-7600.

Insightful Corporation. 2001. S-Plus 6 for Windows, Seattle, WA.

Jackson, O. 1990. Introduction to expert systems. Addison-Wesley Publishers, Reading, MA

Kaufmann, P.R., P. Levine, E.G. Robinson, C. Seelinger, and D.V. Peck. 1999. Quantifying physical habitat in wadeable streams. EPA/620/R-99/003. U.S. Environmental Protection Agency, Washington, D.C.

Knopp, C. 1993. Testing indices of cold-water fish habitat. North Coast Regional Water Quality Control Board in cooperation with the California Department of Forestry and Fire Protection.

Moyer, C., K.Gallo, N. Dachtler, J. Lloyd, E. Moberly, and D. Simmons. 2001. Aquatic and Riparian Effectiveness Monitoring Program, 2000 Annual Progress Report.

Reeves, G.H., D.B. Hohler, D.P. Larsen, D.E. Busch, K. Kratz, K. Reynolds, K.F. Stein, T. Atzet, P. Hays, and M Tehan. 2001. Aquatic and riparian effectiveness monitoring program for the Northwest Forest Plan. Pre-Publication Draft. Corvallis, OR.

Reynolds, K.M., M. Jensen, J. Andreasen, and I. Goodman. 2000. Knowledge-based assessment of watershed condition. Computers and Electronics in Agriculture. 27: 315-333.

Roper, B.B. and D.L. Scarnecchia, 1995. Observer variability in classifying habitat types in stream surveys. North American Journal of Fisheries Management. 15: 49-53.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22: 169-199.

Taylor, J.K. and T.W. Stanley. 1983. Quality assurance for environmental measurements. Proceedings of the conference on quality assurance for environmental measurements. 1983 Aug 8-12; Boulder, CO. ASTM Special Technical Publication 867 5-11.

[USFS] United States Forest Service Region 6. 2001. Stream Inventory Handbook. Version 2.1. Portland, OR.

[USDA-USDI] U.S. Department of Agriculture, Forest Service and Department of the Interior, Bureau of Land Management. 1994. Record of decision for amendments to Forest Service and Bureau of Land management planning documents within the range of the northern spotted owl and standards and guidelines for management of habitat for late-success ional and old-growth related species within the range of the northern spotted owl. Washington DC.

Van Sickle, J. and R.M. Hughes. 2000. Classification strengths of ecoregions, catchments, and geographic clusters for aquatic vertebrates in Oregon. Journal of the North American Benthological Society 19: 370-384.

Waterman, D.A. 1986. A guide to expert systems. Addison-Wesley Publishers, Reading, MA.

Wetzel, R.G. 2000. Limnology. 3rd Edition, Springer-Verlag, New York.

Acknowledgments

The Aquatic and Riparian Effectiveness Monitoring Program is an interagency effort resulting from the contributions of the USDA Forest Service, USDI Bureau of Land Management, US Environmental Protection Agency, National Marine Fisheries Service, US Fish and Wildlife Service, USDI National Park Service, California Indian Forestry and Fire Management Council, Northwest Indian Fisheries Commission, Intertribal Timber Council, and US Army Corps of Engineers. Funding was provided by USDA Forest Service Region 6 and Region 5, USDI Bureau of Land Management, National Marine Fisheries Service, USDI National Park Service, USDI Geological Survey, USDA Pacific Northwest Research Station, and US Environmental Protection Agency.

Dr. Gordon Reeves and David Hohler of the USDA Forest Service provided valuable assistance and advice. We appreciate the statistical guidance provided by Phil Larsen and Tony Olsen of the US Environmental Protection Agency. The Regional Interagency Advisory Team (Appendix B) provided valuable feedback on the 2000 efforts that lead to improvements in the program. Many biologists at the forest and district level provided logistical assistance and valuable insight into many of the watersheds visited, including: Nate Dachtler - Deschutes National Forest (NF); Ken Meyer - Gifford-Pinchot NF, Randle Ranger District (RD); Karen Chang – Mt. Baker-Snoqualamie NF, Darrington RD; Chuti Fielder - Mt.Hood NF, Barlow RD; Mark McHenry – Olympic NF, Quilcene RD; Steve Bachmann - Shasta-Trinity NF, McCloud RD; Carolyn Cook, Karen Kenfield, and Lee Morgan from Six Rivers NF, Rick Golden – Umpqua NF, Diamond Lake; Bob Nichols –Umpqua NF, Tiller RD; Tina Mayo – Wenatchee NF, Naches RD; Tom Mendenhall and Chuck Wheeler - BLM Roseburg; and John Schwabe – California Department of Fish and Game. Dave Fuller and Sam Morrison of the BLM in Arcata

CA drew 6th field lines for their areas in California. USDA Remote Sensing Applications Center in Salt Lake City, UT is interpreting all of the aerial photographs for the riparian vegetation analysis. The Bureau of Land Management Buglab is conducting the laboratory analysis of the benthic macroinvertebrate samples. Loren Bahls, Ph.D. is completing periphyton sample analysis. The Cooperative Chemical Analysis Laboratory at Oregon State University in Corvallis, OR conducted laboratory analysis for water chemistry.

We extend our sincerest thanks to Jon Grunbaum for his assistance while detailing as a field operations leader. Peter Eldred, Travis Hamrick, and Steve Wilcox conducted analyses on upslope and riparian vegetation and roads, and constructed maps for this report. Jake Chambers, Sean Gordon, Amanda Robillard, Devin Simmons, and Jonathan Thompson provided valuable assistance with field data entry and analysis. Field assistance was provided by: Mary Beatty, Rae Benedict, Mike Berger, Jake Chambers, Tim Guildehaus, Erica Gwynn, Travis Hamrick, Wade Hoiland, Kimberly Howard, Mark Isley, Mark Jessop, Kurt Karageorge, Mariah McPherson, David Piatt, Robert Potts, Zack Reeves, Amanda Robillard, Devin Simmons, Nathan Starr, Jonathan Thompson, and Mike Thompson.

Tables

.

Table 1. Watersheds included in 2001 pilot project. Included is the state, county, physiographic province, the National Forest (NF) or Bureau of Land Management District (Dis) that manages the watershed, the watershed name, and the major river system in which the watershed is located.

State	County	Province	Forest or District	Watershed	Major River System
CA	Humboldt	Klamath	Six Rivers NF	Mill Creek	Klamath
CA	Trinity	Klamath	Shasta-Trinity NF	North Fork Swift Creek	Trinity
CA	Shasta	Cascades	Shasta-Trinity NF	Kosk Creek	Pit
CA	Humboldt	Coast	BLM-Kings Dis	Honeydew Creek	Mattole
CA	Shasta	Cascades	Shasta-Trinity NF	Ney Springs	Sacramento
OR	Josephine	Klamath Mts.	Siskiyou NF	Elk Creek	Illinois
OR	Douglas	Cascades West	Umpqua NF	Upper Clearwater River	Umpqua
OR	Douglas	Cascades West	Umpqua NF	Lower Jackson Creek	Umpqua
OR	Jefferson	Cascades East	Deschutes NF	Six Creek	Deschutes
OR	Wasco	Cascades East	Mt. Hood NF	North Fork Mill Creek	Columbia
OR	Douglas	Coast	BLM-Roseburg Dis	Brush Creek	Umpqua
WA	Clallam	Olympic Pennisula	Olympic NF	Copper Creek	Dungeness
WA	Snohomish	West Cascades	Mt. Baker-Snoqualamie	Upper South Fork Stillaguamish River	Stillaguamish
WA	Lewis	West Cascades	Gifford-Pinchot NF	North Fork Tilton River	Nisqually
WA	Okanagan	East Cascades	Okanagan NF	Rattlesnake Creek	Methow
WA	Kittitas	East Cascades	Wenatchee NF	South Fork Taneum Creek	Yakima

Table 2. List of indicators collected during the field effort including intensive, extensive, and quality assurance (QA) surveys.

	Intensive	Extensive	QA
Physical Habitat			
Bankfull width: depth	X	X	X
Gradient	X		X
Sinuosity	X		X
Entrenchment ratio	X	X	X
Substrate D_{50}	X		X
Percent fines	X		X
Wood frequency	X	X	X
Pool frequency	X	X	X
Pool residual depth	X	X	X
Water Chemistry			
Total Kjeldahl nitrogen	X		X
Total phosphorus	X		X
Dissolved oxygen	X		X
Conductivity	X		X
pH	X		X
Temperature	X		X
Biological Sampling			
Periphyton	X		X
Macroinvertebrates	X		X
Amphibians	X		X
Fish	X		X

Table 3. Summary of methods used to collect data on AREMP watershed condition indicators.

Indicator	**Collection**	**Method**
Physical Habitat		
Bankfull Width: depth	Calc.	= bankfull width / mean bankfull depth
Gradient	Calc.	= rise / run of the sample reach
Sinuosity	Calc.	= stream length / valley length
Entrenchment ratio	Calc.	= flood prone width / bankfull width
Substrate D_{50}	Field	Modified Wolman pebble count
Percent fines	Field	Klamath grid
Wood frequency	Field	Tally of wood in sample reach
Pool frequency	Field	Tally of pools in sample reach
Pool residual depth	Calc.	= Pool max depth - pool tail crest depth
Water Chemistry		
Total Kjeldahl nitrogen	Field	Water collected for lab determination
Total phosphorus	Field	Water collected for lab determination
Dissolved oxygen	Field	Multiline P4 meter
Conductivity	Field	Multiline P4 meter
pH	Field	Multiline P4 meter
Temperature	Field	Onset Optic Stowaway data logger
Biological Sampling		
Periphyton	Field	Removal from known substrate area
Macroinvertebrates	Field	Kicknet sampling at each transect
Amphibians	Field	Electrofishing and timed stream bank search
Fish	Field	Electrofishing

Table 4. Evaluation criteria used in the decision support model. Details on curve types are included in Figure 9.

Variable	Curve Type	Lower "poor"	Lower "good"	Upper "good"	Upper "poor"	Source
Habitat						
Pool Frequency	1	Dependent on bankfull width (see text)				1
Wood Frequency	1	Dependent on bankfull width (see text)				1
D50	2	45	65	95	128	2
Fines	1	17	11			3
Temperature	2	5	10	15	21	4
Chemistry						
Dissolved Oxygen	1	6.5	10			5
pH	2	5	6.5	7.5	8.5	6
Total Nitrogen	2	0.30	0.66	0.70	0.75	5
Total Phosphorus	2	0.03	0.08	0.17	0.26	5
Biota						
Aquatic Amphibians	1	0.5	2			
Fish	1	0.5	2			
Terrestrial Amphibians	1	0.5	2			
Riparian Vegetation						
Conifer Early	1	0.4	0.13			7
Conifer Mid	1	0.23	0.39			7
Conifer Late	1	0.18	0.31			7
Deciduous	1	0.02	0			7
Mixed Early	1	0.07	0.01			7
Mixed Mid	1	0.06	0.1			7
Mixed Late	1	0.03	0.05			7
Roads						
Riparian Road Density	1	0.5	0			8
Road Crossing	1	2	0			8
Upslope Road Density	1	3	2			8
Upslope Vegetation						
Conifer Early	1	0.41	0.09			7
Conifer Mid	1	0.27	0.44			7
Conifer Late	1	0.22	0.36			7
Deciduous	1	0.01	0			7
Mixed Early	1	0.05	0.02			7
Mixed Mid	1	0.02	0.03			7
Mixed Late	1	0.03	0.05			7

Sources

1. Bilby and Ward (1991)
2. Knopp (1993)
3. Chapman (1988)
4. Hicks (2000)

5. Wetzel (2000)
6. Oregon Department of Environmental Quality
7. See text for explanation (Methods in EMDS modeling effort section)
8. High Cascades Matrix

Table 5. Evaluation criteria for channel morphological characteristics used in the decision support model. All values are from Rosgen (1994).

Variable	Curve	Lower		Upper	
Channel Type	Type*	"poor"	"good"	"poor"	"good"
Bankfull W:D					
A	1	14	12		
B	1	14	12		
C	1	10	12		
D	1	38	40		
E	1	14	12		
F	1	10	12		
G	1	14	12		
Entrenchment Ratio					
A	1	1.6	1.4		
B	2	1.2	1.4	2.2	2.4
C	1	2	2.2		
D	1	2	2.2		
E	1	2	2.2		
F	1	1.6	1.4		
G	1	1.6	1.4		
Gradient					
A	1	3	4		
B	1	10.9	9.9		
C	1	4.9	3.9		
D	1	4.9	3.9		
E	1	4.9	3.9		
F	1	4.9	3.9		
G	1	4.9	3.9		
Sinuosity					
A	1	1.4	1.2		
B	1	1	1.2		
C	1	1	1.2		
D	1	1.4	1.2		
E	1	1.3	1.5		
F	1	1	1.2		
G	1	1	1.2		

*See Figure 9 for details

Table 6. Examination of the costs per watershed by six major categories of AREMP operation. The columns titled Categories and Subcategories reflect the general areas of and subcategories of AREMP operation, respectively. The Description column describes, in general terms, the type of tasks that makeup an area of operation. The next three columns give the cost per sub-watershed for each of four scenarios: Survey of 16, 32, & 50 sub-watersheds respectively. The final column is a projection of cost per sub-watershed after initial final implementation, i.e., long term operational costs after startup costs are realized. The TOTAL 1 row represents the sum of the six areas of operation for a single sub-watershed. The TOTAL 2 row represents the cost per sub-watershed based on only the Field, Raw Data Processing, Data Analysis, & GIS Support. This total represents the cost per sub-watershed without overhead, fuzzy curve development, etc.

Categories	Subcategories	Description	Cost per watershed @ 16 for pilot	Cost per watershed @ 32 for pilot	Cost per watershed @ 50 full implementation	Cost per watershed @ 50 full implementation
Coordinating Field Logistics		Hiring, training, safety, travel, T&A for field crews; equipment purchasing[1]; acquiring sampling permits	$24,000	$20,000	$19,000	$17,000
Data Processing						
	Raw Data handling	Gathering, checking for errors, & archiving raw data; generating summaries for the EMDS modeling process	$8,000	$6,000	$6,000	$6,000
	EMDS model development	Refining existing models, staying abreast of recent literature & research that is relevant to the AREMP process	$1,000	$1,000	$500	$500

[1] AREMP has already invested approximately $80,000 in equipment during the 2000 & 2001 fiscal years.

Categories	Subcategories	Description	Cost per watershed @ 16 for pilot	Cost per watershed @ 32 for pilot	Cost per watershed @ 50 full implementation	Cost per watershed @ 50 full implementation
	Data Analysis	Processing the field and GIS generated data; analysis for an specialized questions	$2,000	$1,000	$1,000	$1,000
Evaluation criteria maintenance		Staying abreast of the current literature & research relevant to AREMP; acquiring literature relevant to AREMP; analyzing exterior datasets; working with local/regional expert input	$3,000	$2,000	$1,000	$1,000
GIS Support		Development of field maps; processing of upslope data; developing, acquiring & maintaining GIS layers	$10,000	$5,000	$3,000	$2,000
Coordinating with other agencies		Maintaining communication & coordination with other agencies; development of “bridges” between protocols & program needs	$4,000	$2,000	$1,000	$1,000
Overhead costs		Building support, non-field computers,	$6,000	$3,000	$2,000	$2,000

Categories	Subcategories	Description	Cost per watershed @ 16 for pilot	Cost per watershed @ 32 for pilot	Cost per watershed @ 50 full implementation	Cost per watershed @ 50 full implementation
TOTAL 1[2]			$58,000	$40,000	$34,000	$30,000
TOTAL 2[3]			($43,000)	($32,000)	($30,000)	($26,000)

[2] TOTAL 1 represents the full cost of the project divided by the number of subwatersheds.
[3] TOTAL 2 represents only the costs associated with the Field, Raw Data Processing, Data Analysis, and GIS Support

Figures

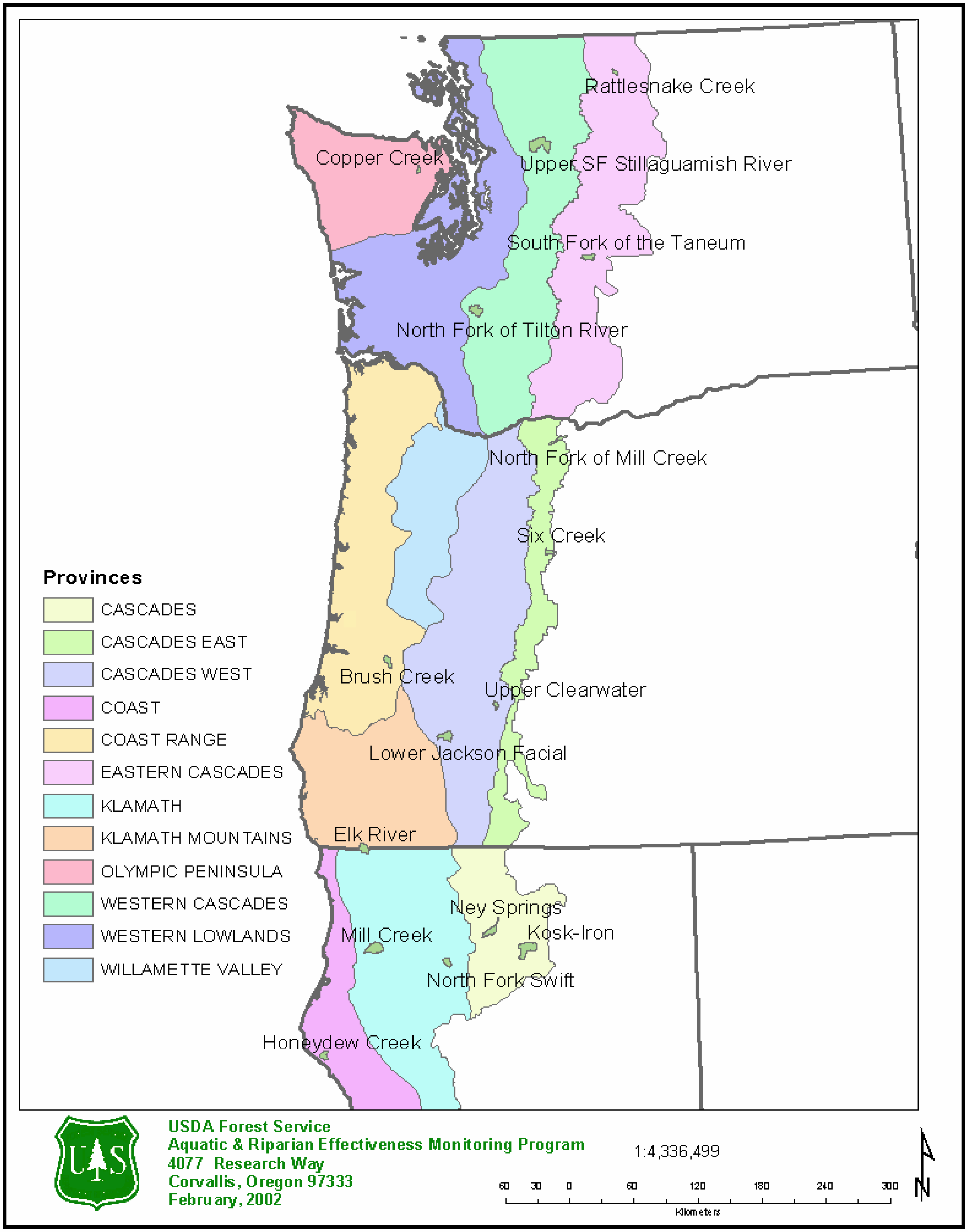


Figure 1. Map of the 16 watersheds included in 2001 pilot project. The provinces of the Northwest Forest Plan are color coded in the background.

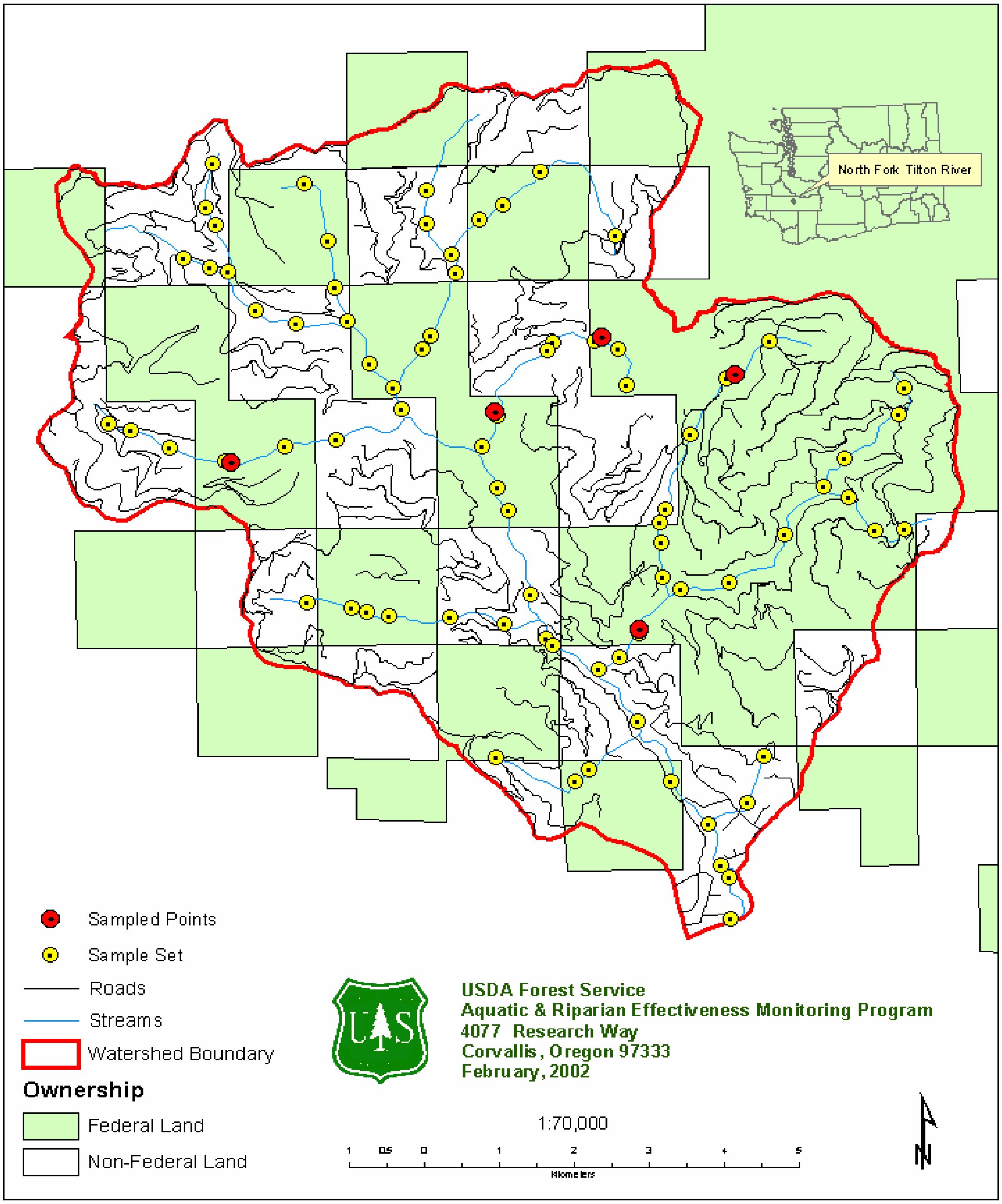


Figure 2. North Fork of the Tilton River in the state of Washington as an example watershed demonstrating the 80 potential sample sites, sites actually sampled, roads, streams, and land ownership.

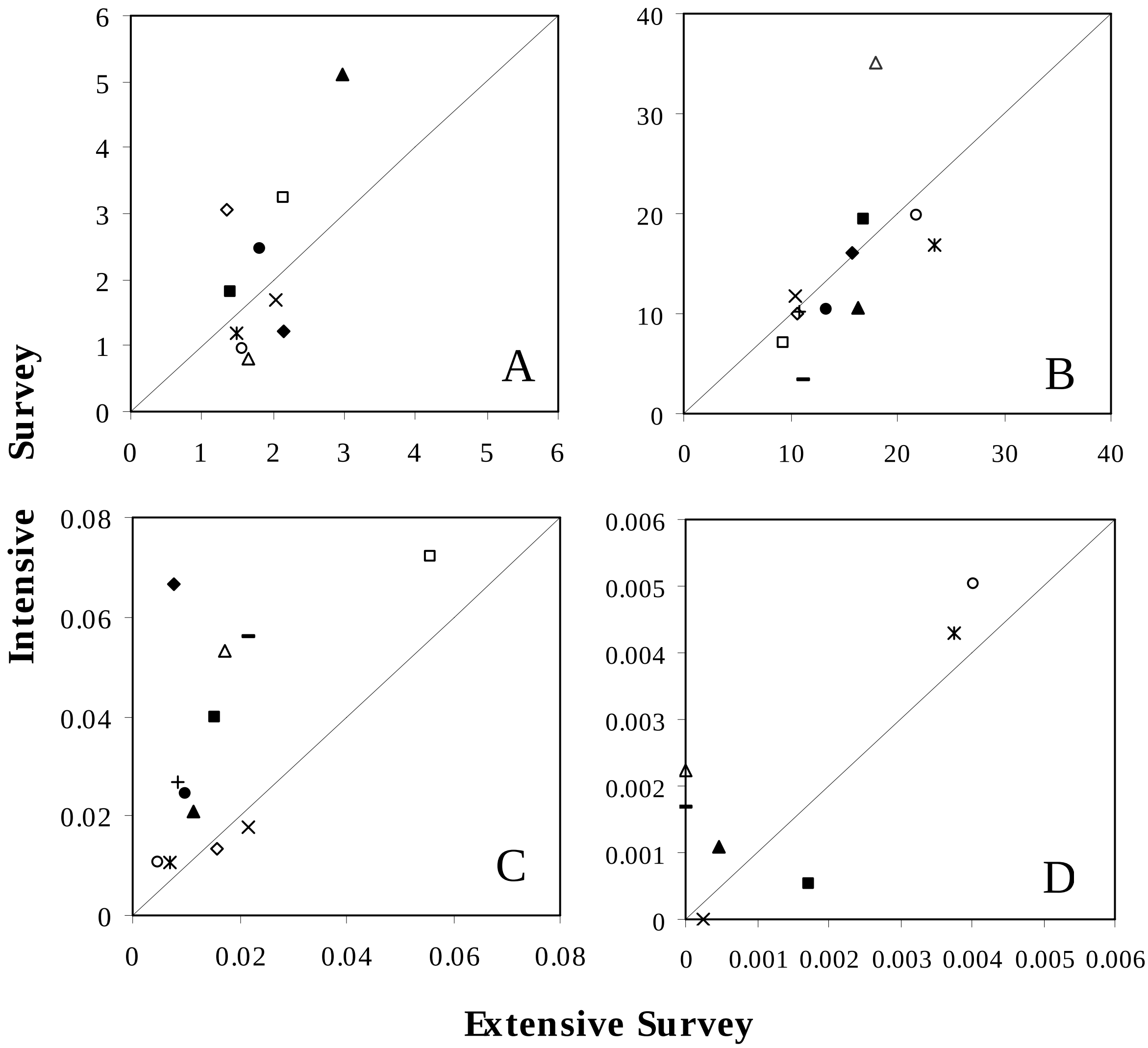


Figure 3. Comparison of extensive and intensive survey data. In all figures, data from the extensive survey are shown on the x-axis and data from the intensive survey are shown on the y-axis. Entrenchment ratio is shown in panel A, bankfull width: depth in panel B, total pool frequency in panel C (# / m), and frequency of pools greater than 1 m deep (# / m) in panel D. Symbols on the figures represent different watersheds, and individual watersheds are represented by the same symbol on all panels. Diagonal lines represent the one to one ratio.

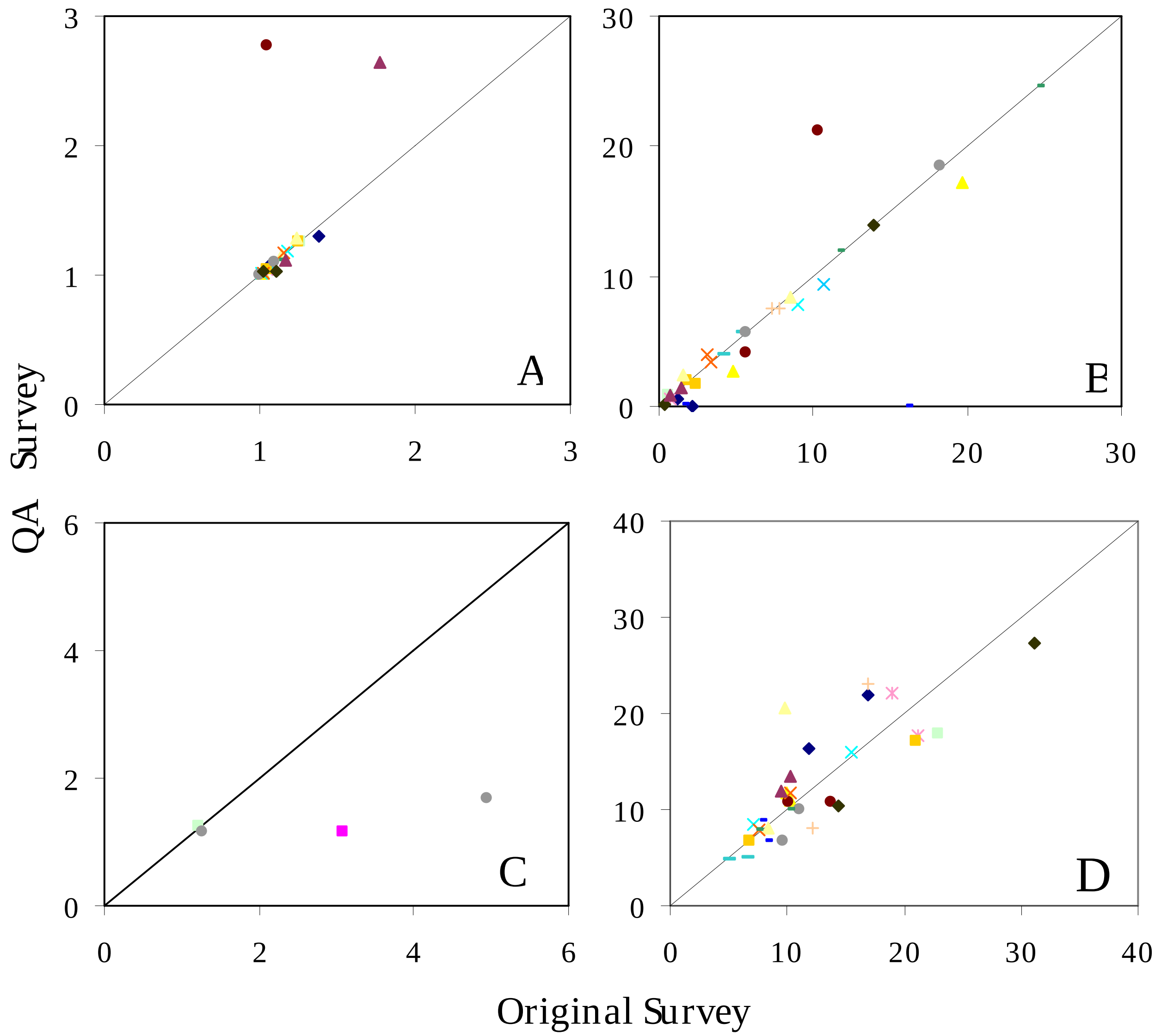


Figure 4. Comparison of original and QA surveys for channel morphology indicators. Sinuosity is shown in panel A, percent slope is shown in panel B, entrenchment ratio is shown in panel C, and bankfull width: depth is shown in panel D. Points represent individual sample sites. Symbols on the figures represent different watersheds, and individual watersheds are represented by the same symbol on all panels. Diagonal lines represent the one to one ratio.

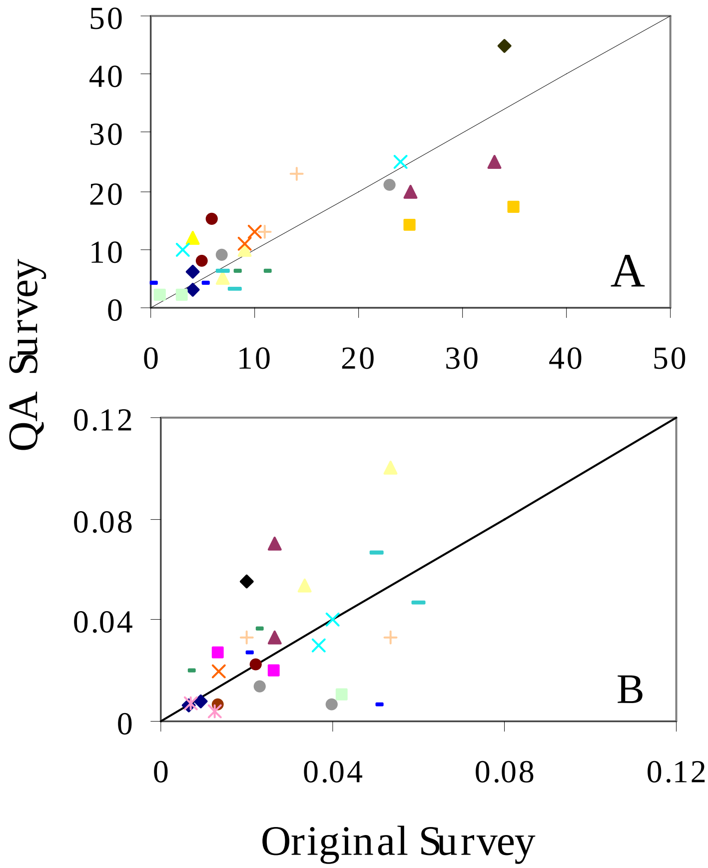


Figure 5. Comparison of original and QA surveys for habitat indicators. Wood frequency is shown in panel A in pieces per 100m, and pool frequency is shown in panel B in number of pools per meter. Points represent individual sample sites. Symbols on the figures represent different watersheds, and individual watersheds are represented by the same symbol on both panels. Diagonal lines represent the one to one ratio.

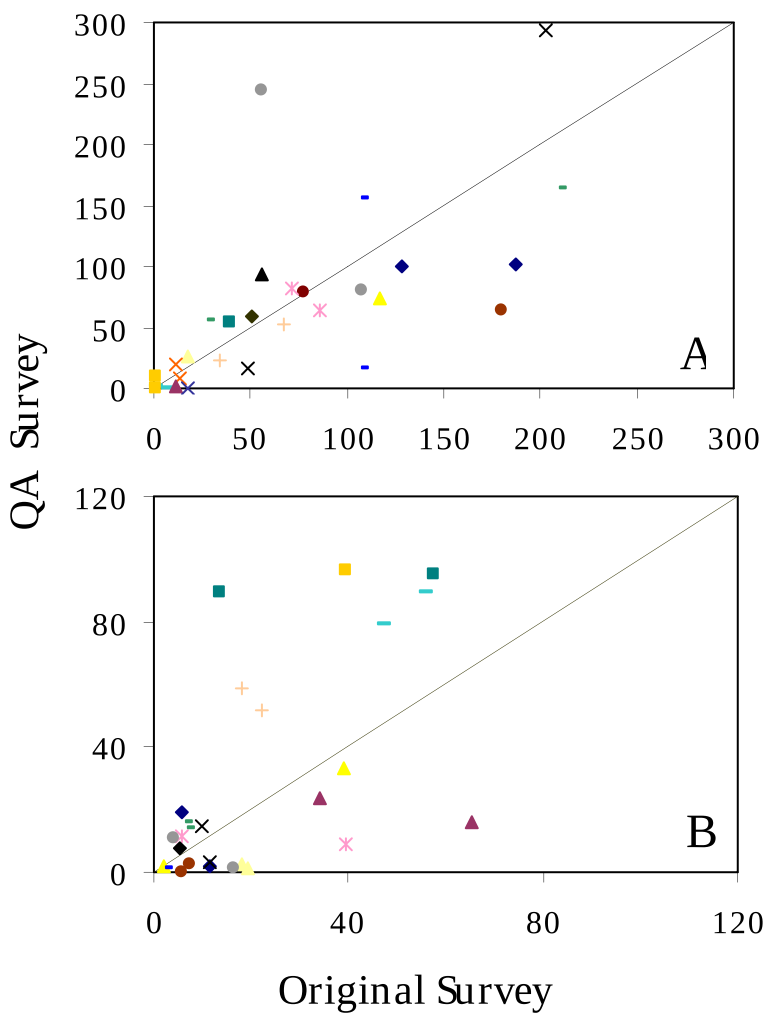


Figure 6. Comparison of original and QA surveys for substrate indicators. D_{50} is shown in panel A, and percent fines is shown in panel B. Points represent individual sample sites. Symbols on the figures represent different watersheds, and individual watersheds are represented by the same symbol on both panels. Diagonal lines represent the one to one ratio**.**

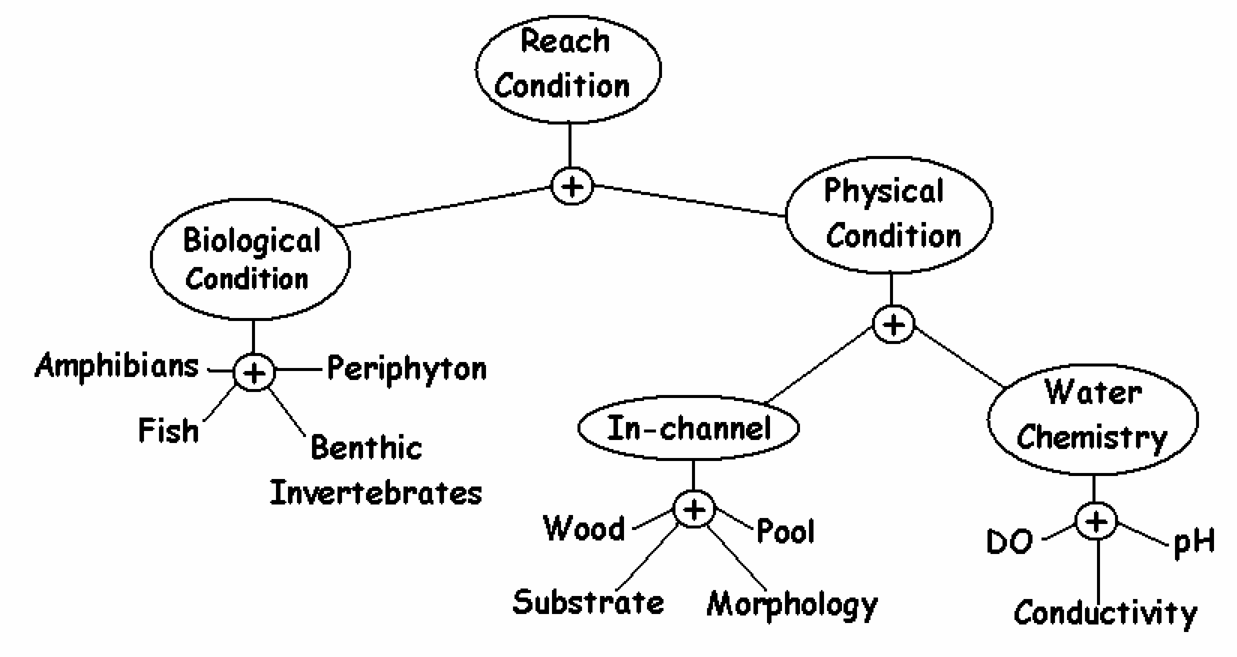


Figure 7. Reach-level knowledge base used in the decision support model. The + operators pass the average evaluation score to the next highest level.

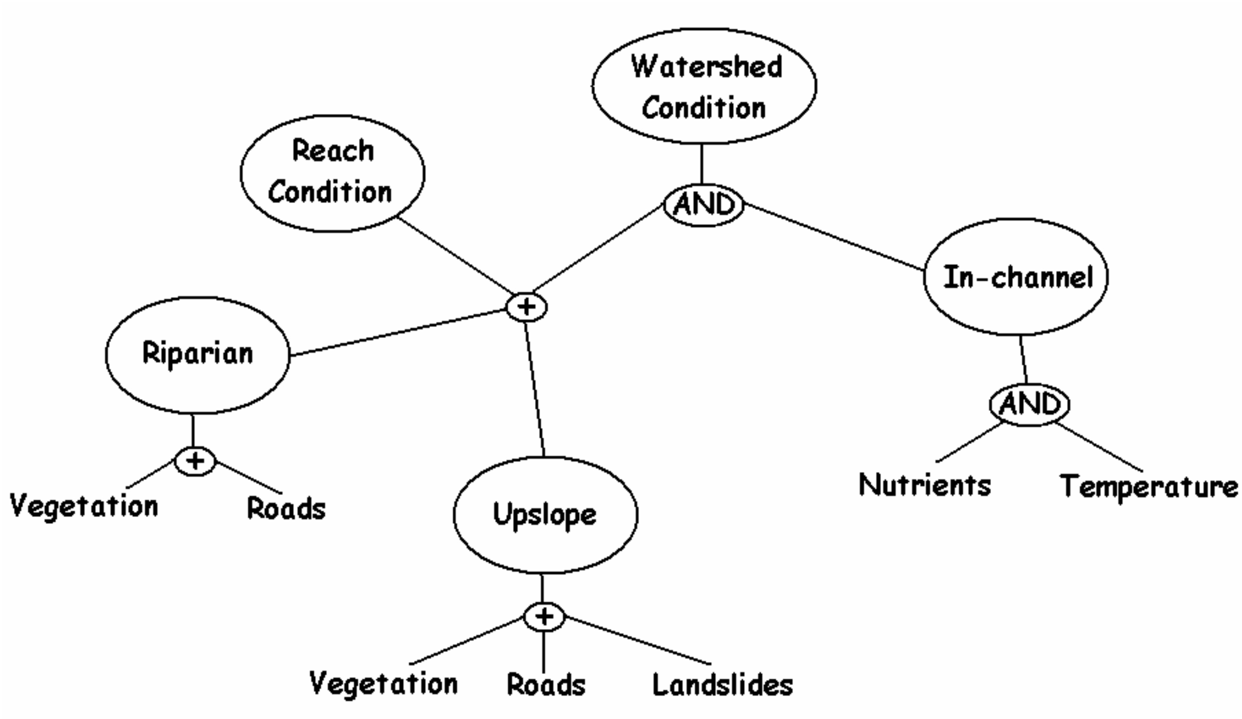


Figure 8. Watershed-level knowledge base used in the decision support model. The AND operators pass the lowest evaluation score, and + operators pass the average evaluation score to the next highest level. The reach condition group is the average across reaches within a watershed, as calculated in the reach knowledgebase shown in Figure 7.

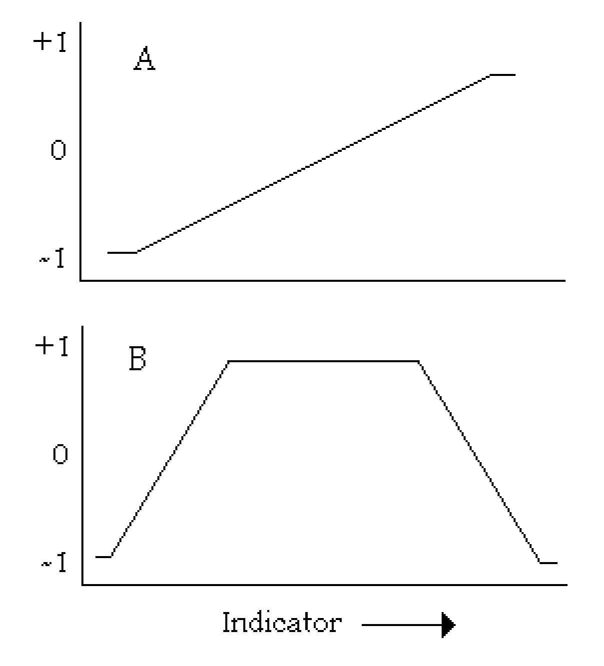


Figure 9. Types of fuzzy curves used in the decision support model. A type 1 fuzzy curve is shown in panel A, and a type 2 fuzzy curve is shown in panel B. On the y-axis, +1 represents the indicator value that is “good”, and –1 represents the indicator value that is “poor”.

Appendices

Appendix A. Synopsis of field sampling protocols.

Introduction

The Aquatic Riparian Effectiveness Monitoring Program (AREMP) was developed to monitor aquatic and riparian ecosystems on federal lands managed under the Northwest Forest Plan. The purpose of the AREMP module is to determine the current condition of 6^{th} field watersheds and track the changes in watershed condition over time. A total of 250 watersheds will be monitored under AREMP, with 50 watersheds sampled each year over a five-year period.

Field data collected will provide information on both the physical habitat and the biota. Physical habitat indicators include: bankfull width to depth ratio, entrenchment ratio, pool frequency, sinuosity, gradient, wood frequency, percent fines, and substrate D_{50}. Discharge and water chemistry data were also collected. Biological indicators include: periphyton, benthic macroinvertebrates, aquatic and terrestrial amphibians, and fish.

The stream data will be combined with upslope and riparian information (primarily vegetation and road density) to provide an estimate of watershed condition. Condition will be determined using a decision support model that aggregates all indicators. The stream data collected in the field represent about 2/3 of the data included in the decision support model.

Site Selection

For the 2001 pilot, sixteen 5^{th} field HUC (Hydrologic Unit Code) watersheds that contained a minimum of 25 % federal land were randomly selected throughout the Northwest Forest Plan area. A 6^{th} field HUC was randomly chosen within each of these 5^{th} fields. Sixth-field watersheds were excluded from the analyses only if they did not contain at least 25%

federal ownership along the stream channel. In future efforts, 6th fields will be selected randomly and the 5th field selection step will be omitted.

Eighty potential sampling sites were randomly chosen along the stream network in the 6th field watershed. In the field, sites were considered for sampling beginning with number 1 and continuing through the list, omitting sites that could not be sampled.

The **only** reasons that sites cannot be sampled include:

- The site is located on private land or cannot be accessed due to private land.
- The site is not safely accessible; i.e., the site cannot be reached without putting the crew in danger. Long hikes down into steep canyons do *not* qualify.
- The stream is too small or not physically samplable. The minimum stream size is about 1 meter (3 feet) wide (wetted width) and 0.1 meters (4 inches) deep in riffle habitats.
- The stream is too large to physically sample (i.e.,not wadeable) and is a safety concern for crews.
- The site is located in a lake or pond.

The goal was to sample a total of eight sites within a watershed: four in constrained, and four in nonconstrained reaches. The length of the site was determined as 20* the bankfull width, with minimum and maximum reach lengths of 150 and 500 m, respectively. Nonconstrained reaches were defined as reaches that have an entrenchment ratio (flood prone width / bankfull width) larger than 2.2, and a slope gradient less than 3 %. Constrained reaches have entrenchment ratio less than 2.2, and slope gradient greater than 3 %.

Physical Habitat Mapping

Cross-sectional profiles

Channel cross-sectional and longitudinal profiles were mapped in each sample site using a laser rangefinder. Cross-sectional profile information was used to calculate bankfull width to depth ratios and entrenchment ratios. In nonconstrained reaches, 11 cross sections were mapped, equally spaced along the length of the sample reach. The downstream-most cross section was monumented. Mapping the monumented cross-section began outside flood prone. Outside bankfull, shots were taken as needed to capture slope changes. Inside bankfull, 20 points were measured on an increment based on the bankfull width. Additional shots were taken at both wetted edges and at the thalweg. At each of the ten remaining cross sections, 11 shots were taken on increment within the bankfull prism, with measurements taken at both wetted edges and the thalweg (Figure 10). Of these ten cross sections, two randomly selected profiles extended beyond flood prone to determine flood prone width. Only one point was taken outside bankfull in the remaining cross sections. In the constrained reaches, six profiles were mapped, none of which were monumented. Each of these was mapped as described for the cross sections in nonconstrained reaches that are not monumented.

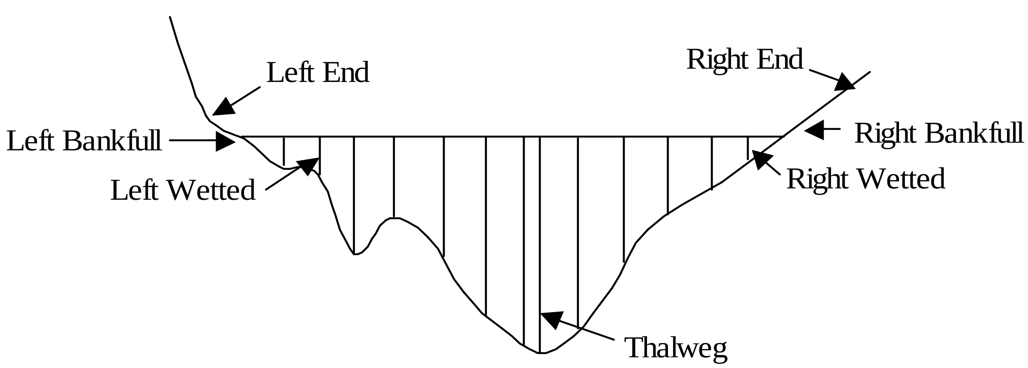


Figure 10. Example cross sectional profile with point labeling (looking downstream).

Longitudinal Profiles

Longitudinal profiles are used to calculate sinuosity, gradient, and pool frequency at all sample sites by shooting points with the laser rangefinder. Shots were taken on an increment that was approximately 1/100 of the sample site length. Additional measurements were taken at pool tail crests, maximum pool depth, and pool head. The same protocol was used in all sample reaches, constrained or nonconstrained.

Substrate

The protocol for measuring substrate is the same as that used by the Environmental Protection Agency's Environmental Monitoring and Assessment Program (Peck et al. 1999). In nonconstrained reaches, 11 substrate measurements were taken at each of the 11 transects. Substrate measurements were taken on evenly spaced increments within the bankfull channel. In constrained reaches, measurements were taken at each of the six transects, and at five intermediate transects as well. The intermediate transects were set up midway between the primary transects (Peck et al. 1999). Percent fines was measured in the tails of scour pools as described by the USDA Forest Service Region 5 SCI protocol (1998). Three measurements were taken using a Klamath grid in each pool tail in the reach.

Large Wood

The large wood protocol was adapted from that used in the Oregon Department of Fish and Wildlife's Stream Habitat Surveys (Moore et al. 1999). Within each reach, pieces of large wood were counted if they had a minimum length of 3 m and were at least 0.3 m in diameter at breast height (DBH). Length and DBH were estimated for each piece. Measurements of length and DBH were taken on the first 10 pieces in the reach and every 5th piece thereafter. In addition, notes were made on the location within the channel, whether the piece was natural or artificial (i.e.,had a cut end or was part of a man-made structure), and whether the piece was single or part of an accumulation. Large wood in jams (defined as five or more pieces) was not measured, however the presence of the jam and its approximate size was documented.

Other Chemical and Physical Parameters

Discharge was taken at one location within the sample site using a flow meter. Water samples for nutrient analyses (total Kjeldahl nitrogen and total phosphorus) were taken at one location within the watershed, at the lowest point in the watershed on federal land. Additional information on temperature, dissolved oxygen, pH, and conductivity was collected at each sample site. All of these physical and chemical data were used as support data for the biological sampling. An overview of the sampling is shown in Figure 11.

Biological Sampling

Periphyton

The periphyton protocol used for both field collection and lab analysis is the same as that outlined by the EPA EMAP (Peck et al. 1999). Benthic periphyton samples were collected at all sites. The sampling protocol is the same for both constrained and nonconstrained reaches. At each transect, periphyton was removed from a 12-cm^2 area. Subsamples from the transects were composited into a single sample for the reach.

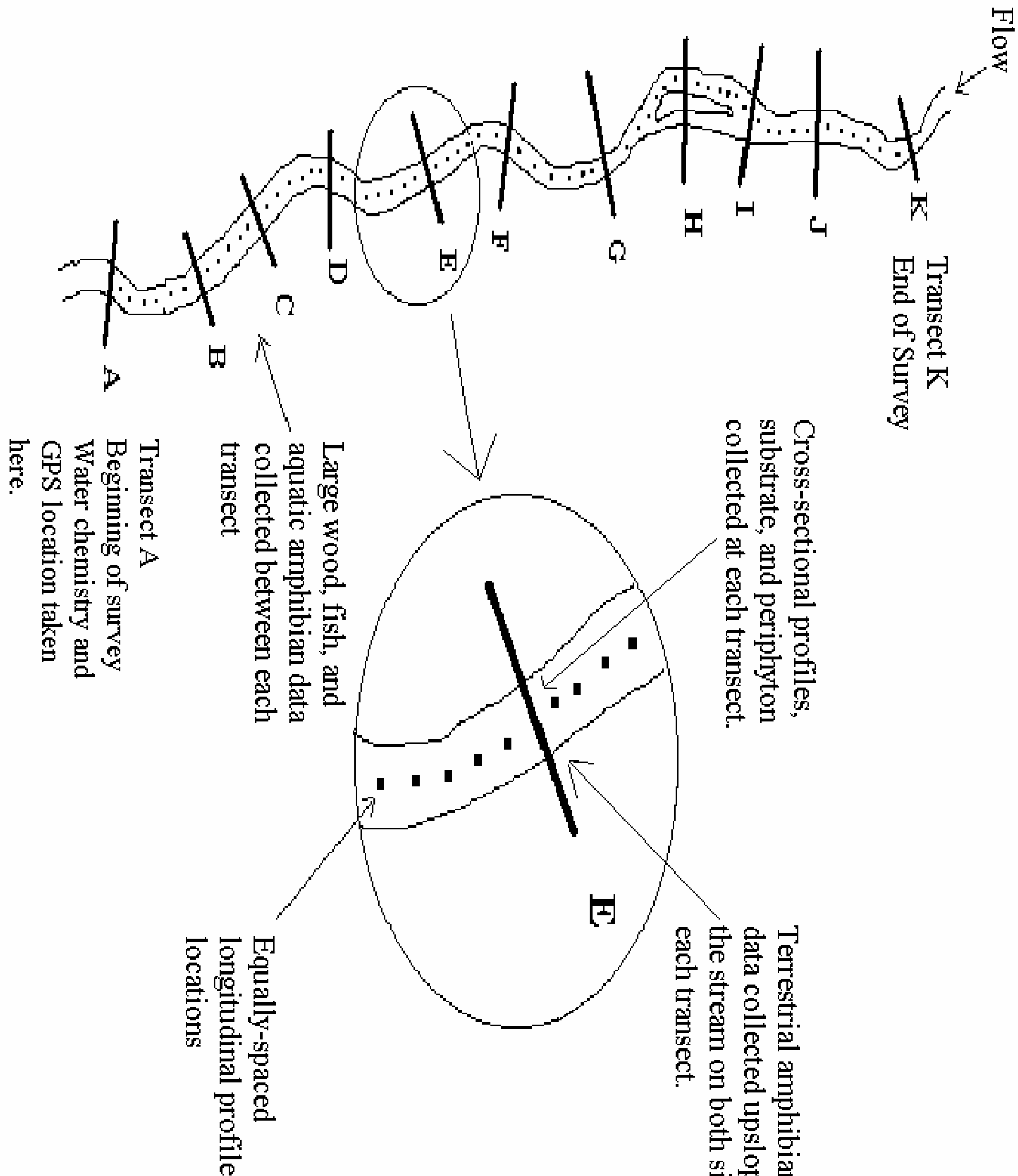


Figure 11. Overview of site layout including sampling strategy for nonconstrained sample sites.

Benthic Macroinvertebrates

The benthic invertebrate protocol is the same as that described by Hawkins et al. (2001) for the River InVertebrate Prediction And Classification System (RIVPACS) sampling program. Benthic invertebrate samples were collected at all sites. The sampling protocol is the same for both constrained and nonconstrained reaches. Two subsamples were taken in each of four riffles in the reach using a kick net. The eight subsamples were composited into a single sample for the reach.

Fish and Aquatic Amphibians

Fish and aquatic amphibian sampling was conducted at all sites within specified watersheds. The same sampling protocol was used in both constrained and nonconstrained reaches. At each site, a single pass with an electroshocker was conducted between each transect. All animals were identified and enumerated. Approximately 10-20 % of the fish were measured, and their condition was estimated using displacement. Snout-vent lengths were measured for all aquatic amphibians. Snorkeling was used to determine fish and aquatic amphibian presence where TES fish species were present.

Terrestrial Amphibians

Time and area-constrained searches were conducted for terrestrial amphibians at each site within the watershed. At each transect, searches began at the wetted edge and continued up the bank on either side of the stream for five minutes (ten minutes total at each transect). Special attention was given to seeps, springs, or other hot spots. Snout-vent lengths were measured for all captured amphibians.

Extensive Survey

A customized version of the Hankin and Reeves (1988) stream survey protocol was developed for collection of stream habitat data on ten of the 18 watersheds sampled during the AREMP 2001 pilot. The objectives of this survey are to collect data on pool frequency, residual pool volume, large wood, bankfull width, and flood prone width for the entire basin. These data will be compared with the data collected in the intensive survey as a methodological comparison.

Surveyors will begin at the mouth of the creek, or the lowest potion of the stream that is on federal land, ensuring that surveys are not conducted on any private land. The survey will include the area up to the top of the watershed or until the stream channel is too small to sample (less than 1 m wide and less than 10 cm deep at the pool tail crest). The survey should be extended above the upper-most intensive sampling location, at the very least. Surveys will be conducted on the mainstem as well as any tributaries sampled in the intensive survey.

Every habitat unit encountered was classified as either pool or riffle. Following the standard definition of the pool that was stated earlier, each habitat unit was classified as pool or riffle (non-pool). For each pool or riffle, the surveyors obtained estimates of the lengths and average bankfull widths as well as maximum pool depth (Pool Max D) and pool tail crest (PTC Depth) for pool units. To obtain a calibration ratio, the first 10 units were measured and then every tenth pool and riffle measured to be used in correcting the estimated units.

These measurements are comprised of length of the unit, bankfull (BF) width and flood prone width (meters) in 3 locations, ¼, ½, and ¾ of the total length of the habitat unit (Figure 12). A measurement of bankfull depth, will be taken by extending a measuring tape across the channel with depth measurements taken at three equally spaced increments along the tape (at ¼,

½, and ¾ of the bankfull width). Additional measurements were taken at the thalweg (maximum bankfull depth) and at 2 * maximum bankfull depth equal to flood prone (FP) depth.

In addition to the classification and measurement of channel units, we have collected information on the large present in each system. These data were obtained following the same guidelines stated earlier and will be used in a comparison with the intensive data. GPS waypoints were taken at the beginning and end of the surveys to demarcate property boundaries, tributary junctions, culverts, bridges, and other major landmarks. This data will be incorporated as GIS layers in the future and can be used to later identify specific reaches of the stream.

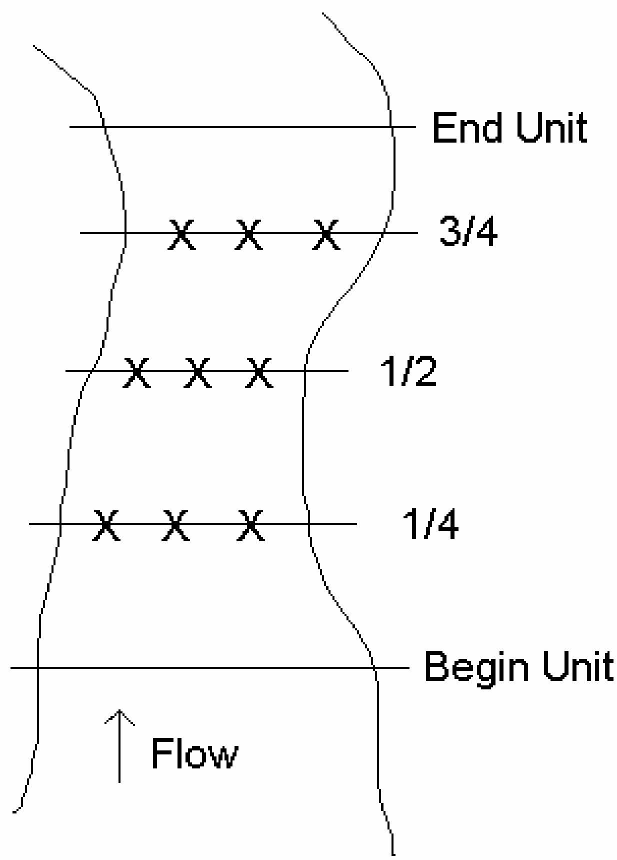


Figure 12. Location of bankfull width and depth measurements within habitat units. Bankfull and flood prone width measurements should be taken at ¼, ½, and ¾ of the length of the unit. Bankfull depth should be taken at ¼, ½, and ¾ of the bankfull width (indicated by X), with an additional depth location taken at the thalweg.

References

Hankin, D.G. and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45: 834-844.

Hawkins, C.P., J. Ostermiller, and M. Vinson. 2001. Stream invertebrate, periphyton, and environmental sampling associated with biological water quality assessments. Field Protocols. Utah State University, Logan, UT.

Moore K, K. Jones and J. Dambacher. 1999. Methods for stream habitat surveys, aquatic habitat inventory project, Natural Production Program: Oregon Department of Fish and Wildlife, Corvallis, OR.

Peck, D.V., J.M. Lazorchak, and D.J. Klemm (editors). 1999. Unpublished draft. Environmental monitoring and assessment program – surface waters: Western pilot study field operations manual for wadeable streams. EPA/XXX/X-XX/XXXX. U.S. Environmental Protection Agency, Washington, D.C.

USDA Forest Service, Region 5. 1998. Stream Condition Inventory Guidebook. Version 4.0.

Appendix B. Members of the Regional Interagency Advisory Team.

Member	Agency Affiliation
Dave Busch	USGS-BRD
Bruce Davies	NWIFC
Al Doelker	BLM (Oregon)
Dave Fuller	BLM (California)
Joseph Furnish	USFS-Region 5
Mike Furniss	USFS-PNW
Reed Glesne	NPS -- North Cascades
Bob Gresswell	USGS-BRD
Dave Heller	USFS-Region 6
Terry Hofstra	NPS -- Redwood
Dave Hohler	USFS
Phil Kaufmann	EPA Research
Deborah Konnoff	USFS-Region 6
Kim Kratz	NMFS
Phil Larsen	EPA Research
Steve Leider	WDFW
Rosy Mazaika	BLM (Oregon)
Bruce McCammon	USFS-Region 6
Bruce McIntosh	ODFW Research
John Meyner	NPS -- Olympic
Joe Moreau	BLM (Oregon)
Kathy Moynan	USF&WS
Tony Olsen	EPA Research
Dave Powers	EPA
Steve Ralph	EPA Region X
John Rector	USFS-Region 5
Gordie Reeves	USFS-PNW
Keith Reynolds	USFS-PNW
Dave Schuett-Hames	NWIFC
George Smith	Intertribal Timber Council
Gary Stacey	CDFG
Larry Week	CDFG